ROBBINSVILLE PUBLIC SCHOOLS

OFFICE OF CURRICULUM AND INSTRUCTION

Robbinsville High School

AP Physics C

Board of Education

Curriculum Writing Committee

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BOARD OF EDUCATION INITIAL ADOPTION DATE: 9/27/22

Course Philosophy

AP Physics C allows students to apply and strengthen their mathematical reasoning skills by applying them to tangible phenomena through experimental and theoretical approaches. This course is to mirror the rigor one would find in a college-level physics course designed for STEM majors. AP Physics C provides the opportunities to solidify and apply calculus to discover the intricacies of Dynamics as described by Isaac Newton as well as the foundations of Electromagnetism. Students in this course will develop the bedrock for advanced skills they will apply throughout their college careers.

Course Description

AP Physics C is a laboratory-based course covering both AP C Mechanics and AP C Electricity and Magnetism. Included are Kinematics, Forces, Energy, Momentum, Rotation, Oscillations, Gravity, Electric Charge, Gauss' Law, Electric Potential, DC Circuits, Magnetostatics, and Induction. All areas of study will be approached through laboratory experience, derivations, and practice materials, and will develop the scientific skills as put forth by the College Board for this AP course.

Core and Supplemental Instructional Materials

Core Materials	Supplemental Materials
• Physics for Scientists and Engineers - Randall D. Knight	• Pearson Mastering Physics • Pivot Interactives • PhET Interactives • NJCTL Materials • AP Classroom Materials

AP Physics C

Unit Title	Unit Understandings and Goals	Recommended Duration/ Pacing	Assessments
1. Kinematics	a. Determine the appropriate expressions for velocity and position as a function of time for an object accelerating uniformly in one dimension with given initial conditions. b. Calculate unknown variables of motion such as acceleration, velocity, or positions for an object undergoing uniformly accelerated motion in one dimension. c. Calculate values such as average velocity or minimum or maximum velocity for an object in uniform acceleration. Determine functions of position, velocity, and acceleration that are consistent with each other, for the motion of an object with a nonuniform acceleration. a. Calculate the components of a velocity, position, or acceleration vector in two dimensions. b. Calculate a net displacement of an object moving in two dimensions. c. Calculate a net change in velocity of an object moving in two dimensions. d. Calculate an average acceleration vector for an object moving in two dimensions. e. Calculate a velocity vector for an object moving relative to another object (or frame of reference) that moves with a uniform velocity. f. Describe the velocity vector for one object relative to a second object with respect to its frame of reference.	9 Blocks	Formative · Do now feedback · Exit ticket feedback · Formative worksheets · Teacher and peer feedback Summative · 1-D Kinematics Test · 2-D Kinematics Test Common Benchmark Assessments (mid/end of course) · Mid-year Mechanics Test · AP Test · Course final exam · Course culminating project Alternative Assessments (projects, etc when appropriate) · Constant motion Lab · Falling Chain Lab · Projectiles Lab · Circular Motion Demonstrations

	Describe the motion of an object in two-dimensional motion in terms of the consistency that exists between position and time, velocity and time, and acceleration and time.		
2. Newton's Laws of Motion	Describe an object (either in a state of equilibrium or acceleration) in different types of physical situations such as inclines, falling through air resistance, Atwood machines, or circular tracks). a. Calculate the velocity of an object moving in a horizontal circle with a constant speed, when subject to a known centripetal force. b. Calculate relationships among the radius of a circle, the speed of an object (or period of revolution), and the magnitude of centripetal acceleration for an object moving in uniform circular motion. a. Describe the forces of interaction between two objects (Newton's third law). b. Describe pairs of forces that occur in a physical system due to Newton's third law. c. Describe the forces that occur between two (or more) objects accelerating together (e.g., in contact or connected by light strings, springs, or cords).	10 Blocks	Formative · Do now feedback · Exit ticket feedback · Formative worksheets · Teacher and peer feedback Summative · 1-D Forces Test · 2-D Forces Test Common Benchmark Assessments (mid/end of course) · Mid-year Mechanics Test · AP Test · Course final exam · Course culminating project Alternative Assessments (projects, etc when appropriate) · Atwood's Machine Lab · Drag Lab · Projectile drag simulations · Circular Motion simulations
3. Work, Energy, and Power	a. Calculate work done by a given force (constant or as a given function F(x)) on an object that undergoes a specified displacement. b. Describe the work done on an object as the result of the scalar product between force and displacement. c. Explain how the work done on an object by an applied force acting on an object can be negative or zero. a. Compare conservative and dissipative forces. b. Describe the role of a conservative force or a dissipative force in a dynamic system.	6 Blocks	Formative · Do now feedback · Exit ticket feedback · Formative worksheets · Teacher and peer feedback Summative · Energy Test Common Benchmark Assessments (mid/end of course) · Mid-year Mechanics Test · AP Test · Course final exam · Course culminating project

	a. Describe physical situations in which mechanical energy of an object in a system is converted to other forms of energy in the system. b. Describe physical situations in which the total mechanical energy of an object in a system changes or remains constant. a. Derive an expression for the rate at which a force does work on an object. b. Calculate the amount of power required for an object to maintain a constant acceleration. c. Calculate the amount of power required for an object to be raised vertically at a constant rate.		Alternative Assessments (projects, etc when appropriate) · Kiss the Egg Lab · Work and Energy Lab
4. Systems of Particles and Linear Momentum	a. Calculate the center of mass of a system of point masses or a system of regular symmetrical objects. b. Calculate the center of mass of a thin rod of nonuniform density using integration. a. Calculate the total momentum of an object or a system of objects. b. Calculate relationships between mass, velocity, and linear momentum of a moving object. a. Calculate the velocity of one part of a system after an explosion or a collision of the system. b. Calculate energy changes in a system that undergoes a collision or an explosion.	4 Blocks	Formative · Do now feedback · Exit ticket feedback · Formative worksheets · Teacher and peer feedback Summative · No Test · Possible short summative project Common Benchmark Assessments (mid/end of course) · Mid-year Mechanics Test · AP Test · Course final exam · Course culminating project Alternative Assessments (projects, etc when appropriate) · Center of Mass Activity · Impulse of a falling chain · Momentum of collisions lab
5. Rotation	a. Calculate the magnitude and direction of the torque associated with a given force acting on a rigid body system. b. Calculate the torque acting on a rigid body due to the gravitational force. a. Derive the moment of inertia, using calculus, of a thin rod of uniform density about an arbitrary axis perpendicular to the rod. b. Derive the moment of inertia, using calculus, of a thin rod of nonuniform density about an arbitrary axis perpendicular to the rod.	7 Blocks	Formative · Do now feedback · Exit ticket feedback · Formative worksheets · Teacher and peer feedback Summative · Rotation test Common Benchmark Assessments (mid/end of course) · Mid-year Mechanics Test · AP Test · Course final exam

	c. Derive the moments of inertia for a thin cylindrical shell or disc about its axis or an object that can be considered to be made up of coaxial shells (e.g., annular ring). a. Explain how the angular kinematic relationships for uniform angular acceleration are directly analogous to the relationships for uniformly and linearly accelerated motion. b. Calculate unknown quantities such as angular positions, displacement, angular speeds, or angular acceleration of a rigid body in uniformly accelerated motion, given initial conditions. c. Calculate unknown quantities such as angular positions, displacement, angular velocity, or rotational kinetic energy of a rigid body rotating with a specified nonuniform angular acceleration. a. Describe the complete analogy between fixed axis rotation and linear translation for an object subject to a net torque. b. Calculate unknown quantities such as net torque, angular acceleration, or moment of inertia for a rigid body undergoing rotational acceleration. c. Calculate the angular acceleration of an extended rigid body, of known moment of inertia, about a fixed axis or about its center of mass when it is experiencing a specified net torque due to one or several applied forces. a. Calculate the angular impulse acting on a rotating rigid body given specified angular properties or forces acting over time intervals. b. Calculate the angular momentum vector of a rotating rigid body in cases in which the vector is parallel to the angular velocity vector.		· Course culminating project Alternative Assessments (projects, etc when appropriate) · Hoop and Disc Race · Unknown Rotational Inertia Lab
6. Oscillations and Gravitation	a. Describe the general behavior of a spring-mass system in SHM in qualitative terms. b. Describe the relationship between the phase angle and amplitude in an SHM system.	6 Blocks	Formative · Do now feedback · Exit ticket feedback · Formative worksheets · Teacher and peer feedback

	Derive a differential equation to describe Newton's second law for a spring-mass system in SHM or for the simple pendulum. Describe the kinetic energy as a function of time (or position), potential energy as a function of time (or position), and total mechanical energy as a function of time (or position) for a spring-mass system in SHM, identifying important features of the oscillating system and where these features occur. Calculate the magnitude of the gravitational force between two large spherically symmetrical masses. Calculate quantitative properties (such as period, speed, radius of orbit) of a satellite in circular orbit around a planetary object.		Summative · Oscillations Test · Gravity Project Common Benchmark Assessments (mid/end of course) · Mid-year Mechanics Test · AP Test · Course final exam · Course culminating project Alternative Assessments (projects, etc when appropriate) · SHO equations activity · Physical Pendulum Lab · Gravitational Potential Energy Simulation Lab
7. Electrostatics	Describe behavior of charges or system of charged objects interacting with each other. Using the definition of electric field, unknown quantities (such as charge, force, field, and direction of field) can be calculated in an electrostatic system of a point charge or an object with a charge in a specified electric field. Calculate the value of the electric potential in the vicinity of one or more point charges. a. State and apply the general definition of electric flux. b. Calculate the electric flux through an arbitrary area or through a geometric shape (e.g., cylinder, sphere). c. Calculate the flux through a rectangular area when the electric field is perpendicular to the rectangle and is a function of one position coordinate only. Derive expressions for the electric field of specified charge distributions using integration and the	8 Blocks	Formative · Do now feedback · Exit ticket feedback · Formative worksheets · Teacher and peer feedback Summative · Coulomb's Law Test · Gauss' Law Test Common Benchmark Assessments (mid/end of course) · Mid-year Mechanics Test · AP Test · Course final exam · Course culminating project Alternative Assessments (projects, etc when appropriate) · Coulomb's Law Lab · Charge on tape · PhET Electric Field · PhET Electric Potential

	principle of superposition. Examples of such charge distributions include a uniformly charged wire, a thin ring of charge (along the axis of the ring), and a semicircular or part of a semicircular arc.		
8. Conductors, Capacitors, and Dielectrics	a. Recognize that the excess charge on a conductor in electrostatic equilibrium resides entirely on the surface of a conductor. b. Describe the consequence of the law of electrostatics and that it is responsible for the other law of conductors (that states there is an absence of an electric field inside of a conductor). a. Apply the general definition of capacitance to a capacitor attached to a charging source. b. Calculate unknown quantities such as charge, potential difference, or capacitance for physical system with a charged capacitor. Describe and/or explain the physical properties of an insulating material when the insulator is placed in an external electric field.	5 Blocks	Formative · Do now feedback · Exit ticket feedback · Formative worksheets · Teacher and peer feedback Summative · No test - possible lab practical Common Benchmark Assessments (mid/end of course) · Mid-year Mechanics Test · AP Test · Course final exam · Course culminating project Alternative Assessments (projects, etc when appropriate) · Resistivity Lab · Construct a Capacitor Lab
9. Electric Circuits	a. Calculate unknown quantities relating to the definition of current. b. Describe the relationship between the magnitude and direction of current to the rate of flow of positive or negative charge. a. Derive expressions that relate current, voltage, and resistance to the rate at which heat is produced in a resistor. b. Calculate different rates of heat production for different resistors in a circuit. a. Identify parallel or series arrangement in a circuit containing multiple resistors. b. Describe a series or a parallel arrangement of resistors.	4 Blocks	Formative · Do now feedback · Exit ticket feedback · Formative worksheets · Teacher and peer feedback Summative · DC Circuits Test Common Benchmark Assessments (mid/end of course) · Mid-year Mechanics Test · AP Test · Course final exam · Course culminating project Alternative Assessments (projects, etc when appropriate) · Internal Resistance Lab · Capacitance Investigation · Circuit Puzzles

	a. Calculate the equivalent capacitance for capacitors arranged in series or parallel, or a combination of both, in steady-state situations. b. Calculate the potential differences across specified capacitors arranged in a series in a circuit. c. Calculate the stored charge in a system of capacitors and on individual capacitors arranged in series or in parallel.		· RC Circuits
10. Magnetics Fields	a. Calculate the magnitude and direction of the magnetic force of interaction between a moving charged particle of specified charge and velocity moving in a region of a uniform magnetic field. b. Describe the direction of a magnetic field from the information given by a description of the motion or trajectory of a charged particle moving through a uniform magnetic field. c. Describe the conditions that are necessary for a charged particle to experience no magnetic force of interaction between the particle and the magnetic field. a. Calculate the magnitude of the magnetic force acting on a straight-line segment of a conductor with current in a uniform magnetic field. b. Describe the direction of the magnetic force of interaction on a segment of a straight current-carrying conductor in a specified uniform magnetic field. a. Calculate the magnitude and direction of a magnetic field produced at a point near a long, straight, current-carrying wire. b. Apply the right-hand rule for magnetic field of a straight wire (or correctly use the Biot–Savart Law found in CNV-8.A.1) to deduce the direction of a magnetic field near a long, straight, current-carrying wire. a. Describe the direction of the contribution to the magnetic field made by a short (differential) length	5 Blocks	Formative · Do now feedback · Exit ticket feedback · Formative worksheets · Teacher and peer feedback Summative · Magnetic Fields Test Common Benchmark Assessments (mid/end of course) · Mid-year Mechanics Test · AP Test · Course final exam · Course culminating project Alternative Assessments (projects, etc when appropriate) · Magnetic Field of a slinky lab · Magnetic Field strength lab · Magnetic field strength of Earth lab

	of straight segment of a current-carrying conductor. b. Calculate the magnitude of the contribution to the magnetic field due to a short (differential) length of a straight segment of a current-carrying conductor.		
11. Electromagnetism	a. Calculate the magnetic flux through a loop of regular shape with arbitrary orientation in relation to the magnetic-field direction. b. Calculate the magnetic flux of the field due to a current-carrying, long, straight wire through a rectangular-shaped area that is in the plane of the wire and oriented perpendicularly to the field. c. Calculate the magnetic flux of a non-uniform magnetic field that may have a magnitude that varies over one coordinate through a specified rectangular loop that is oriented perpendicularly to the field. a. Derive the expression for the inductance of a long solenoid. b. Calculate the magnitude and the sense of the EMF in an inductor through which a changing current is specified. c. Calculate the rate of change of current in an inductor with a transient current. a. Explain how a changing magnetic field can induce an electric field. b. Associate the appropriate Maxwell's equation with the appropriate physical consequence in a physical system containing a magnetic or electric field.	5 Blocks	Formative · Do now feedback · Exit ticket feedback · Formative worksheets · Teacher and peer feedback Summative · Faraday's Law Test Common Benchmark Assessments (mid/end of course) · Mid-year Mechanics Test · AP Test · Course final exam · Course culminating project Alternative Assessments (projects, etc when appropriate) · Faraday's Law lab · RC, LR, and LC circuit labs
12. Conclusions and Summative Project	Research and report on a notable physicist that provides inspiration Explore a notable aspect of physics that has not been explored during the year. Create a short presentation, film, or other representation to discuss this with the class.	10 Blocks	Formative · Do now feedback · Exit ticket feedback · Formative worksheets · Teacher and peer feedback

			Summative · Unit culminating project presentation
			Common Benchmark Assessments (mid/end of course) · Mid-year Mechanics Test · AP Test · Course final exam · Course culminating project
			Alternative Assessments (projects, etc when appropriate) N/A

Unit 1: Kinematics

Enduring Understandings:	**Essential Questions:**
• **There are relationships among the vector quantities of position, velocity, and acceleration for the motion of a particle along a straight line.** • **There are multiple simultaneous relationships among the quantities of position, velocity, and acceleration for the motion of a particle moving in more than one dimension with or without net forces.**	• How can mathematical representations, specifically through calculus, accurately describe the motion of an object? • How can different graphical representations of movement describe the motion of an object and how can they be utilized? • How can we utilize derivatives and integrals to analyze the information contained within position, velocity, and acceleration graphs?

Interdisciplinary Connections

RST.11-12.1 - Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

MP.2 - Reason abstractly and quantitatively

MP.4 - Model with mathematics

Standard Number & Description		**Content, Themes, Concepts, and Skills**	**Teaching Strategies**	**Instructional Resources and Materials**	**Assessment Strategies**
HS-PS2-1	Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.	Motion in one dimension • Concepts ○ Differentiation and integration are necessary for determining functions that relate position, velocity, and acceleration for an object with nonuniform acceleration. ○ Position, velocity, and acceleration versus time for a moving object are related to each other and depend on an understanding of slope, intercepts, asymptotes, and	Desktop Experiment Provide students with a pull-back toy car and a means to take video, and have them record position versus time data for the car as it speeds up and slows down. Have students fit a cubic polynomial to the position-time data and use calculus to predict the car's maximum speed and initial and final magnitude of acceleration. Desktop Experiment Give students a ball launcher, right-triangular block, and meterstick. Have them calculate	Resources • Knight textbook • AP Classroom • HyperPhysics • PhET Simulations • Pivot Interactives simulations • Physics Classroom simulations	Daily Do Nows Teacher and peer feedback Exit Tickets Individual activity guided worksheets Lab reports and lab notebook checks Progress checks

PS2.A	Newton's second law accurately predicts changes in the motion of macroscopic objects.	area or upon conceptual calculus concepts. ● Skills ○ Describe the physical meaning (includes identifying features) of a representation. ○ Describe the relationship between different types of representations of the same physical situation. ○ Select and plot appropriate data. ○ Identify and describe patterns and trends in data or a graph. ○ Linearize data and/or determine a best fit line or curve. ○ Select an appropriate law, definition, mathematical relationship, or model to describe a physical situation. ○ Make a scientific claim. Motion in two dimensions ● Concepts ○ All of the kinematic quantities are vector quantities and can be resolved into components (on a given coordinate system). ○ Motion in two dimensions can be analyzed using the kinematic equations if the motion is separated into vertical and horizontal components. ● Skills ○ Demonstrate consistency between different types of representations of the same physical situation.	the launch speed of the ball using a horizontal launch of the ball from the launcher, then predict where the ball will land if the ball is launched on the triangular block. Changing Representations Give students a verbal description of segmented motion, such as "accelerates from rest at 5 m/s2 for 10 seconds, then comes to rest again after another 20 seconds." Have students draw position/velocity/acceleration graphs and formulate piecewise position/velocity/acceleration equations of motion. Create a Plan Find data for speed and total stopping distance for cars. Provide students with five pairs of speed and total stopping distances (not broken into thinking and braking distances). Ask students to determine from the data the driver's reaction time and the car's braking acceleration. Graph and Switch Student A creates a horizontal and vertical pair of velocity graphs for projectile motion, and Student B must write a narrative of what happens (including whether the projectile was shot at an angle, landed higher or lower, or at the same height).	● Mastering Physics Materials ● PASCO data sensors ● PASCO motion carts and tracks ● PASCO Sparkvue software ● Students supplied devices (Phones, laptops)	Unit summative test Project rubrics
ETS1.A	Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.				

		○ Determine the relationship between variables within an equation when an existing variable changes. ○ Extract quantities from narratives or mathematical relationships to solve problems. ○ Support a claim with evidence from experimental data.			

Unit 2: Newton's Laws

Enduring Understandings:	**Essential Questions:**
• **A net force will change the translational motion of an object.** • **The motion of some objects is constrained so that forces acting on the object cause it to move in a circular path.** • **There are force pairs with equal magnitude and opposite directions between any two interacting objects.**	• How can we visualize forces, and what approaches can we take to analyze the forces acting on an object? • How is it possible that an object moves at a constant speed while accelerating and what kind of motion is this? • Where do we see representations of Newton's Third Law in real life, and how does this affect how we analyze the forces acting on an object?

Interdisciplinary Connections

RST.11-12.1 - Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

MP.2 - Reason abstractly and quantitatively

MP.4 - Model with mathematics

Standard Number & Description		**Content, Themes, Concepts, and Skills**	**Teaching Strategies**	**Instructional Resources and Materials**	**Assessment Strategies**
HS-PS2-1	Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.	Newton's First and Second Laws • Concepts ○ Newton's second law can be applied to an object in accelerated motion or in a state of equilibrium. ○ The direction of friction can be determined by the relative motion between surfaces in kinetic frictional cases.	Desktop Experiment Drill a small hole in the center of a wooden meterstick so that a pencil point fits in the hole. Place a penny on the meterstick and gently rotate the meterstick faster and faster until the penny slips. Have students make measurements and calculations to find the coefficient of static friction between the meterstick and the penny.	Resources • Knight textbook • AP Classroom • HyperPhysics • PhET Simulations • Pivot Interactives simulations	Daily Do Nows Teacher and peer feedback Exit Tickets Individual activity guided worksheets

PS2.A	Newton's second law accurately predicts changes in the motion of macroscopic objects.	◦ Because the resistive force is a function of velocity, applying Newton's second law correctly will lead to a differential equation for velocity. • Skills ◦ Describe the physical meaning (includes identifying features) of a representation. ◦ Make observations or collect data from representations of laboratory setups or results. ◦ Represent features of a model or the behavior of a physical system using appropriate graphing techniques, appropriate scale, and units. ◦ Demonstrate consistency between different graphical representations of the same physical situation. ◦ Select an appropriate law, definition, mathematical relationship, or model to describe a physical situation. ◦ Make a scientific claim. ◦ Support a claim with evidence from experimental data. Circular Motion • Concepts ◦ In order for an object to undergo circular motion in any context, there must be a force, multiple forces, or components of forces acting in the radial direction. These forces can be represented	Graph and Switch Student A produces a free-body diagram. Student B is to suggest a situation where the forces on an object would be described by that diagram. Discussion Groups Have students explain why a strong man will win against a small child in tug-of-war, even though the rope always has the same tension at both ends. Have students support their reasoning with free-body diagrams. Desktop Experiment Ask students to find the coefficient of friction (static or kinetic) of a shoe or other object. This activity can be made into a competition, where the team with the simplest procedure or the team that uses the least equipment wins. Desktop Experiment Give students an object having unknown-mass (or have students use their set of house keys, if available), known masses, string, pulley, meterstick, and stopwatch. Have students determine the unknown mass of the object.	• Physics Classroom simulations • Mastering Physics Materials • PASCO data sensors • PASCO motion carts and tracks • PASCO Sparkvue software • Students supplied devices (Phones, laptops)	Lab reports and lab notebook checks Progress checks Unit summative test Project rubrics
ETS1.A	Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.				

		with appropriate free-body diagrams. ● Skills ○ Describe the relationship between different types of representations of the same physical situation. ○ Determine the relationship between variables within an equation when a new variable is introduced. ○ Apply an appropriate law, definition, or mathematical relationship to solve a problem. Newton's Third Law ● Concepts ○ To analyze a complete system of multiple connected masses in motion, several applications of Newton's second law in conjunction with Newton's third law may be necessary. This may involve solving two or three simultaneous linear equations. ● Skills ○ Demonstrate consistency between different types of representations of the same physical situation. ○ Determine the relationship between variables within an equation when a new variable is introduced. ○ Determine or estimate the change in a quantity using a mathematical relationship. ○ Support a claim with evidence from physical representations.			

		○ Provide reasoning to justify			

Unit 3: Work, Energy, and Power

Enduring Understandings:	**Essential Questions:**
● **When a force is exerted on an object, and the energy of the object changes, then work was done on the object.** ● **Conservative forces internal to the system can change the potential energy of that system.** ● **The energy of a system can transform from one form to another without changing the total amount of energy in the system.** ● **The energy of an object or a system can be changed at different rates.**	● How do forces affect the energy of a system? ● What is work? How can this concept be more useful than analyzing the forces acting upon a system? ● How does the concept of energy transfer assist engineers in designing things like roller coasters, cars, etc.? ● How can we utilize the concept of power to analyze the ways that we utilize energy in our daily lives?

Interdisciplinary Connections

SL.11-12.5 - Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

HSN-Q.A.2 - Define appropriate quantities for the purpose of descriptive modeling.

Standard Number & Description		**Content, Themes, Concepts, and Skills**	**Teaching Strategies**	**Instructional Resources and Materials**	**Assessment Strategies**
HS-PS3-1	Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.	Work-Energy Theorem ● Concepts ○ The component of the displacement that is parallel to the applied force is used to calculate the work. ○ The area under the curve of a force versus position graph is equivalent to the work done on the object or system. ● Skills ○ Identify a testable scientific question or problem.	Bar Chart Present students with a sequence of two or three energy bar charts and have them describe a realistic situation that would involve those energy transformations. Students must also draw a diagram of the situation. Graph and Switch Student A constructs a potential energy (PE) function that has at least one minimum and a graph of that function. Student B formulates	Resources ● Knight textbook ● AP Classroom ● HyperPhysics ● PhET Simulations ● Pivot Interactives simulations ● Physics Classroom simulations	Daily Do Nows Teacher and peer feedback Exit Tickets Individual activity guided worksheets Lab reports and lab notebook checks Progress checks

HS-PS3-2	Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).	○ Support a claim with evidence from physical representations. Forces and Potential Energy ● Concepts ○ A force can be defined as a conservative force if the work done on an object by the force depends only on the initial and final position of the object. ● Skills ○ Select relevant features of a representation to answer a question or solve a problem. ○ Demonstrate consistency between different graphical representations of the same physical situation. ○ Extract quantities from narratives or mathematical relationships to solve problems. Conservation of Energy ● Concepts ○ If only forces internal to the system are acting on an object in a physical system, then the total change in mechanical energy is zero. ● Skills ○ Identify or describe potential sources of experimental error. ○ Select relevant features of a graph to describe a physical situation or solve problems. ○ Determine the relationship between variables within an equation when a new variable is introduced.	AP-level questions about the PE function (i.e., “If a 2 kg mass is released at x = 3 m, what is its speed at x = 9 m?”) that Student C must answer. Desktop Experiment Using spring-loaded suction cup launchers, have students measure the spring constant of the spring, not by removing the spring from the launcher, but by measuring some aspect of the suction cup's motion after being launched. Identify Subtasks Have students construct graph of power delivered to a car as a function of time as the car accelerates from rest and reaches full speed. Next, ask students to determine the car’s mass and its velocity as a function of time. Changing Representations Have each student describe an everyday activity that involves the transfer of mechanical energy. Students then construct energy bar charts showing the exchanges of energy and free-body diagrams to show the forces doing work, and flowcharts to show the flow of energy from one system or form to another.	● Mastering Physics Materials ● PASCO data sensors ● PASCO motion carts and tracks ● PASCO Sparkvue software ● Students supplied devices (Phones, laptops)	Unit summative test Project rubrics

		○ Calculate an unknown quantity with units from known quantities by selecting and following a logical computational pathway. ○ Explain the connection between experimental results and larger physical principles, laws, or theories. Power ● Concepts ○ Power is defined by the following expressions ■ $P = \frac{dE}{dt}$ ■ $P = \overline{F} \cdot \overline{v}$ ● Skills ○ Determine or estimate the change in a quantity using a mathematical relationship.			

Unit 4: Systems of Particles and Linear Momentum

Enduring Understandings:	**Essential Questions:**
• **The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass.** • **An impulse exerted on an object will change the linear momentum of the object.** • **In the absence of an external force, the total momentum within a system can transfer from one object to another without changing the total momentum in the system.**	• Why is the center of mass of a system important for defining the momentum? • How can we utilize the concept of impulse to design systems that mitigate the harmful effects of collisions? • How can we prove that internal forces do not affect the momentum of a system?

Interdisciplinary Connections

HSN-Q.A.1 - Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

HSN-Q.A.2 - Define appropriate quantities for the purpose of descriptive modeling.

Standard Number & Description		**Content, Themes, Concepts, and Skills**	**Teaching Strategies**	**Instructional Resources and Materials**	**Assessment Strategies**
HS-PS2-2	Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.	Center of Mass • Concepts ○ A symmetrical, regular solid of uniform mass density has a center of mass at its geometric center. ○ If there is no net force acting on an object or a system, the center of mass does not accelerate; therefore, the velocity of the center of mass remains unchanged. • Skills ○ Apply an appropriate law, definition, or mathematical	Four-Square Problem Solving Present students with some problem where an object's motion changes (such as a car on an on-ramp entering a freeway). Have students determine the force applied to the object using Newton's laws of motion, work-energy theorem, and impulse-momentum theorem. The fourth square is a free-body diagram. Desktop Experiment Give students two spring-loaded carts with different mass First, have students determine the amount of	Resources • Knight textbook • AP Classroom • HyperPhysics • PhET Simulations • Pivot Interactives simulations • Physics Classroom simulations	Daily Do Nows Teacher and peer feedback Exit Tickets Individual activity guided worksheets Lab reports and lab notebook checks Progress checks
HS-PS2-3	Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.				

HS-PS3-1	Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.	relationship to solve a problem. Impulse and Momentum • Concepts ◦ For a single object moving with some velocity, momentum is defined as: $\overline{p} = m\overline{v}$ ◦ Impulse is defined as the average force acting over a time interval. ◦ A collection of objects with individual momenta can be described as one system with one center of mass velocity. • Skills ◦ Demonstrate consistency between different types of representations of the same physical situation. ◦ Identify appropriate experimental procedures to test a claim or prediction (which may include a sketch of a lab setup). ◦ Determine or estimate the change in a quantity using a mathematical relationship. Conservation of Linear Momentum/Collisions • Concepts ◦ Total momentum is conserved in the system and momentum is conserved in each direction in the absence of an external force. ◦ Forces internal to a system do not change the momentum of the center of mass. ◦ In the absence of a net external force during an interaction, linear momentum is conserved.	kinetic energy gained by Cart 1 when launched by its spring. Then, have students make Cart 1 collide elastically with Cart 2 and predict where Cart 2 will land when it rolls off of the track. Desktop Experiment Using two bathroom scales and a long wooden plank, have students determine the location of their center of mass. Have students determine how far their center of mass moves as they move their arms from their sides to up over their head. Desktop Experiment Give students a device that fires a projectile much faster than can be measured directly using distance and time data. Students are to fire the projectile into a stationary, freely movable object; make necessary measurements, and use conservation of momentum to determine the launch speed of the projectile.	• Mastering Physics Materials • PASCO data sensors • PASCO motion carts and tracks • PASCO Sparkvue software • Students supplied devices (Phones, laptops)	Unit summative test Project rubrics

		- Skills - Describe the effects of modifying conditions or features of a representation of a physical situation. - Derive a symbolic expression from known quantities by selecting and following a logical algebraic pathway. - Provide reasoning to justify a claim using physical principles or laws. - Explain the connection between experimental results and larger physical principles, laws, or theories. - Explain how potential sources of experimental error may affect results and/or conclusions.			

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Enduring Understandings:

- **When a physical system involves an extended rigid body, there are two conditions of equilibrium—a translational condition and a rotational condition.**
- **There are relationships among the physical properties of angular velocity, angular position, and angular acceleration.**
- **A net torque acting on a rigid extended body will produce rotational motion about a fixed axis.**
- **In the absence of an external torque, the total angular momentum of a system can transfer from one object to another within the system without changing the total angular momentum of the system.**

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Essential Questions:

- How is the concept of torque considered when designing and utilizing levers?
- What parallels can be drawn between linear and angular kinematics and momentum?
- How can we apply Newton's Laws to rotating systems?
- In what ways can we utilize linear and rotational approaches to analyze the motion of a system?

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Interdisciplinary Connections

RST.11-12.1 - Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

MP.2 - Reason abstractly and quantitatively

MP.4 - Model with mathematics

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<table>
<tr><th colspan="2">Standard Number & Description</th><th>Content, Themes, Concepts, and Skills</th><th>Teaching Strategies</th><th>Instructional Resources and Materials</th><th>Assessment Strategies</th></tr>
<tr><td>HS-PS2-1</td><td>Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its</td><td>Torque and Rotational Statics
● Concepts
○ The definition of torque is $\overline{\tau} = \overline{r} \times \overline{F}$
○ The calculus definition of moment of inertia is $I = \int r^2 dm$
● Skills</td><td>Desktop Experiment
Students allow a yo-yo to fall and unroll. Have them use a meterstick and stopwatch to determine its downward acceleration. Also have them measure its mass and the radius of its axle and use that information to determine the yo-yo's rotational inertia using rotational dynamics.</td><td>Resources
● Knight textbook
● AP Classroom
● HyperPhysics
● PhET Simulations</td><td>Daily Do Nows

Teacher and peer feedback

Exit Tickets

Individual activity guided worksheets</td></tr>
</table>

	mass, and its acceleration.	○ Make observations or collect data from representations of laboratory setups or results. ○ Represent features of a model or the behavior of a physical system using appropriate graphing techniques, appropriate scale, and units. Rotational Kinematics ● Concepts ○ There are angular kinematic relationships for objects experiencing a uniform angular acceleration. ● Skills ○ Make a claim or predict the results of an experiment. ○ Determine the relationship between variables within an equation when an existing variable changes. ○ Calculate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway. Rotational Dynamics and Energy ● Concepts ○ The rotational analogue to Newton's Second Law is $\overline{\alpha} = \frac{\Sigma\overline{\tau}}{I}$ ○ A complete analysis of a dynamic system that is rolling without slipping can be performed by applying both of Newton's second laws properly to the system. ○ If a rigid body is defined as "rolling," this implies (in the ideal case) that the frictional force does no work on the	Desktop Experiment Have students release a yo-yo from the top of a ramp and allow it to roll down the ramp. Have them use a meterstick and stopwatch to determine the yo-yo's final velocity and the height of its release. Next, have them measure the yo-yo's outer radius and mass and use that information to determine the yo-yo's rotational inertia using energy concepts. Create a Plan Have students complete the necessary research to determine the rotational inertia of a human body in different configurations (arms outstretched, arms pulled in, for example). Then, obtain footage of a figure skater spinning and pulling in her his/arms. Have students analyze the footage to see if angular momentum is conserved. Bar Chart Have students a hoop and a disk (equal mass and radius) down identical ramps. Then have them explain why the disk reached the bottom in less time using energy bar charts and to-scale free-body diagrams. Identify Subtasks Have students design a walkway (of given mass) that is to be suspended from a ceiling. Have them determine the amount of force the two supports (one on each end) must be able to provide as a person (of given mass) walks across the walkway.	● Pivot Interactives simulations ● Physics Classroom simulations ● Mastering Physics Materials ● PASCO data sensors ● PASCO motion carts and tracks ● PASCO Sparkvue software ● Students supplied devices (Phones, laptops	Lab reports and lab notebook checks Progress checks Unit summative test Project rubrics
PS2.A	Newton's second law accurately predicts changes in the motion of macroscopic objects.				
HS-PS3-1	Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.				

		rolling object. The consequence of this property is that in some special cases (such as a sphere rolling down an inclined surface), the conservation of mechanical energy can be applied to the system.
		• Skills
		  ○ Describe the effects of modifying conditions or features of a representation of a physical situation.
		  ○ Sketch a graph that shows a functional relationship between two quantities.
		  ○ Select relevant features of a graph to describe a physical situation or solve problems.
		  ○ Determine or estimate the change in a quantity using a mathematical relationship.
		Angular Momentum and Its Conservation
		• Concepts
		  ○ The definition of angular momentum of a rotating rigid body is $\overline{L} = I\overline{\omega}$
		  ○ The conservation of angular momentum can be applied to many types of physical situations. In all cases, it must be determined that there is no net external torque on the system.
		• Skills
		  ○ Describe the effects of modifying conditions or features of a representation of a physical situation.
		  ○ Derive a symbolic expression from known quantities by selecting and following a logical algebraic pathway.			

		6.D Assess the reasonableness of results or solutions. - Provide reasoning to justify a claim using physical principles or laws.			

Unit 6: Oscillations and Gravity

Enduring Understandings:	Essential Questions:
There are certain types of forces that cause objects to repeat their motions with a regular pattern. **Objects of large mass will cause gravitational fields that create an interaction at a distance with other objects with mass.** **Angular momentum and total mechanical energy will not change for a satellite in an orbit.**	- Where do we see oscillating systems in our daily lives and what aspects do they have in common? - How does the way that we experience gravity on Earth's surface compare to how gravity acts on the scale of the Solar System? The Galaxy? - How does angular momentum in orbital systems allow us to launch spacecraft further into space?

Interdisciplinary Connections

RST.11-12.7 - Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

Standard Number & Description		Content, Themes, Concepts, and Skills	Teaching Strategies	Instructional Resources and Materials	Assessment Strategies
HS-PS2-1	Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.	Simple Harmonic Motion, Springs. and Pendulums - Concepts - The general relationship for SHM is given by the following relationship $x = A\cos(\omega t + \varphi)$ - Using calculus and the position in relation to time relationship for an object in SHM, all three kinematic characteristics can be explored. Recognizing the positions or times where the trigonometric functions have extrema or zeroes can	Changing Representations Students are given a graph of position/velocity/acceleration for SHM and must make the other three graphs with the same time scale, along with force, momentum, kinetic energy, potential energy, and total energy versus time graphs. The students must also make energy bar charts for various instants during the SHM. Desktop Experiment Obtain a steel ruler or yardstick, clamp it to a table, and attach various masses to the end with the hole in it. Have students measure the period of	Resources - Knight textbook - AP Classroom - HyperPhysics - PhET Simulations - Pivot Interactives simulations - Physics Classroom simulations - Mastering Physics	Daily Do Nows Teacher and peer feedback Exit Tickets Individual activity guided worksheets Lab reports and lab notebook checks Progress checks Unit summative test
HS-PS2-4	Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict				

	the gravitational and electrostatic forces between objects.	provide more detail in qualitatively describing the behavior of the motion. ● Skills ○ Describe the effects of modifying conditions or features of a representation of a physical situation. ○ Make a claim or predict the results of an experiment. ○ Explain modifications to an experimental procedure that will alter results. ○ Linearize data and/or determine a best fit line or curve. ○ Explain how the data or graph illustrates a physics principle, process, concept, or theory. ○ Derive a symbolic expression from known quantities by selecting and following a logical algebraic pathway. ○ Explain how potential sources of experimental error may affect results and/or conclusions. Gravitational Forces ● Concepts ○ The magnitude of the gravitational force between two masses can be determined by using Newton's universal law of gravitation. ○ The gravitational force is proportional to the inverse of distance squared; therefore, the acceleration of an object under the influence of this type of force will be nonuniform.	oscillation for each mass attached, and then use the data to determine the spring constant of the steel ruler. Desktop Experiment Have students use a pendulum to determine the acceleration of gravity in the classroom. The winners are the group whose procedure includes the most components for reducing error (timing multiple periods, linearizing data, very precisely finding the center of mass of the bob, for example). Ranking Give students four to six cases of a mass on a spring. The cases show different masses, spring constants, and oscillation amplitudes (m/k/2A, m/2k/A, and 2m/k/2A, for example). Have students rank them based on period, frequency, maximum speed, maximum acceleration, maximum force, and total energy. Predict and Explain Have students predict whether a ball rolling back and forth inside a spherical bowl is SHM. Have them take data to show whether this is SHM (period independent of amplitude or motion is a sine function or force proportional to displacement). Identify Subtasks Have students research the structure of the Earth (specifically the density and depth of the various layers of the Earth: crust, mantle, outer core, inner core) and then calculate what the gravitational field strength must be at the boundary of each layer.	Materials ● PASCO data sensors ● PASCO motion carts and tracks ● PASCO Sparkvue software ● Students supplied devices (Phones, laptops	Project rubrics
HS-PS3-2	Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).				

		● Skills ○ Create appropriate diagrams to represent physical situations. ○ Explain how the data or graph illustrates a physics principle, process, concept, or theory. ○ Derive a symbolic expression from known quantities by selecting and following a logical algebraic pathway. Orbits of Planets and Satellites ● Concepts ○ The centripetal force acting on a satellite is provided by the gravitational force between satellite and planet. ○ Verifying Kepler's third law with actual data provides experimental verification of the law. ○ The total mechanical energy of a satellite is inversely proportional to the orbital distance and is always a negative value and equal to one half of the gravitational potential energy. ○ In all cases of orbiting satellites, the total angular momentum of the satellite is a constant. ● Skills ○ Sketch a graph that shows a functional relationship between two quantities. ○ Determine or estimate the change in a quantity using a mathematical relationship. ○ Calculate an unknown quantity with units from known quantities by selecting	Predict and Explain Have students predict whether an object dropped into a hole drilled into a uniformly-dense, non-rotating planet exhibits simple harmonic motion. Have students show that it does (because the gravitational force is proportional to displacement from the center). Bar Chart Have students create an energy bar-chart for an actual comet or asteroid that orbits the sun. Next, have them research the orbital parameters of the asteroid to make to-scale bar charts. The perihelion should be between 20% and 70% of the aphelion. Desktop Experiment Have students use the My Solar System PhET applet to establish a circular orbit of a planet whose mass is very small compared to the central star. Trying various combinations of radius, speed, star mass, and planet mass (always making a circular orbit), have students show evidence of Newton's Law of Universal Gravitation. Desktop Experiment Have students use the My Solar System PhET applet to establish a circular orbit of a planet whose mass is very small compared to the central star. Trying various combinations of radius and speed (always making a circular orbit), have students show evidence of Kepler's Third Law.		

		and following a logical computational pathway. ○ Explain how potential sources of experimental error may affect results and/or conclusions.			

Unit 7: Electrostatics

Enduring Understandings:	Essential Questions:
Objects with an electric charge will interact with each other by exerting forces on each other. **Objects with electric charge will create electric field** **The total energy of a system composed of a collection of point charges can transfer from one form to another without changing the total amount of energy in the system.** **There are laws that use symmetry and calculus to derive mathematical relationships that can be applied to physical systems containing electrostatic charge.**	- What are some methods we can use to create excess charge on objects and observe Coulomb's Law? - How do electric fields compare and contrast with gravitational fields? - What methods are most useful in defining the appropriate Gaussian surfaces to utilize Gauss' Law?

Interdisciplinary Connections
WHST.9-12.2 - Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

Standard Number & Description		Content, Themes, Concepts, and Skills	Teaching Strategies	Instructional Resources and Materials	Assessment Strategies
HS-PS2-4	Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.	Charge and Coulomb's Law ● Concepts ○ Particles and objects may contain electrostatic charges. The Law of Electrostatics states that like charges repel and unlike charges attract through electrostatic interactions. ○ The presence of an electric field will polarize a neutral object (conductor or insulator). This can create an	Desktop Experiment Give two pith balls some amount of charge (assumed to be equal charges) and hold them near each other. Have students measure the angle their strings make, and use this information to determine the charge on the pith balls. Also, have them determine what fraction of the pith ball's electrons were lost/gained assuming one electron for every $3.3 \times 10{-}27$ kg of mass. Qualitative Reasoning	Resources ● Knight textbook ● AP Classroom ● HyperPhysics ● PhET Simulations ● Pivot Interactives simulations ● Physics Classroom simulations	Daily Do Nows Teacher and peer feedback Exit Tickets Individual activity guided worksheets Lab reports and lab notebook checks Progress checks
HS-PS2-6	Communicate scientific and technical information about why the molecular-level structure is important				

	.in the functioning of designed materials	“induced” charge on the surface of the object. ● Skills ○ Describe the physical meaning (includes identifying features) of a representation. ○ Apply an appropriate law, definition, or mathematical relationship to solve a problem. ○ Calculate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway. Electric Field and Electric Potential ● Concepts ○ The electric field of a single point charge can be determined by using the definition of the electric field and Coulomb’s Law. ○ A charged particle in a uniform electric field will be subjected to a constant electrostatic force. ● Skills ○ Describe the physical meaning (includes identifying features) of a representation. ○ Select and plot appropriate data. ○ Create appropriate diagrams to represent physical situations. ○ Identify and describe patterns and trends in data or a graph. ○ Demonstrate consistency between different graphical representations of the same physical situation. ○ Apply an appropriate law, definition, or mathematical	Have students consider a situation where two metal spheres (one heavy, one light) have unequal-magnitude, opposite charges and are set at rest near each other in space. Students draw acceleration versus time and velocity versus time graphs for the time when the light sphere attracts, collides elastically with, and then repels from the heavier sphere. Changing Representations Have students use the Charges and Fields PhET or the applet at flashphysics.org/electricField.html to investigate electric field and potential (and their relationship) in the vicinity of equal or unequal two- or three-charge systems. Desktop Experiment Connect two electrodes to a 9-V battery and immerse them in a plastic pan of water that is less than 1 cm deep. Use a voltmeter (negative connected to the negative of the battery) to probe the electric potential at various points in the water. Have students construct an electric potential isoline map and estimate the strength of the electric field at various locations. Create a Plan Have students research the electric field strength and direction at ground level on Earth. Next, have them use Gauss’s Law to determine the net charge on Earth.	● Mastering Physics Materials ● PASCO data sensors ● Circuit components: batteries, wires, lightbulbs, multimeters, etc. ● PASCO Sparkvue software ● Students supplied devices (Phones, laptops	Unit summative test Project rubrics
HS-PS3-2	Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).				
HS-PS3-5	Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.				

		relationship to solve a problem. ○ Calculate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway. Electric Potential Due to Point CHarges and Uniform Fields ● Concepts ○ The definition of electric potential at a particular ○ location due to a single point charge is: $V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$ ○ The definition of electric potential at a particular location due to a single point charge is: $\Delta U = q\Delta V$ ○ An electrostatic configuration or field is a conservative field, and the work done in an electric field in moving a known charge through a known electric field is equivalent to the potential energy lost or gained by that charge. Changes in kinetic energy can be determined by using the principle of conservation of energy. ● Skills ○ Describe the relationship between different types of representations of the same physical situation. ○ Select an appropriate law, definition, mathematical relationship, or model to describe a physical situation. ○ Determine the relationship between variables within an			

		equation when an existing variable changes. ○ Determine the relationship between variables within an equation when a new variable is introduced. ○ Apply an appropriate law, definition, or mathematical relationship to solve a problem. ○ Calculate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway. Gauss' Law ● Concepts ○ The general definition of electric flux is: $\Phi = \int \overline{E} \cdot d\overline{A}$ ○ Gauss's Law can be defined in a qualitative way as the total flux through a closed Gaussian surface being proportional to the charge enclosed by the Gaussian surface. The flux is also independent of the size of the Gaussian shape. ● Skills ○ Describe the physical meaning (includes identifying features) of a representation. ○ Select an appropriate law, definition, mathematical relationship, Field and Potentials of other Charge Distributions ● Concepts ○ The electric field of any charge distribution can be			

		determined using the principle of superposition, symmetry, and the definition of electric field due to a differential charge dq. One step in the solution is shown to be: $d\overline{E} = \frac{1}{4\pi\varepsilon_0}\frac{dq}{r^2}\hat{r}$ If this is applied appropriately and evaluated over the appropriate limits, the electric fields of the stated charge distributions can be determined as a function of position. The following charge distributions can be explored using this method: ■ An infinitely long, uniformly charged wire or cylinder determines field at distances along perpendicular bisector ■ A thin ring of charge (along the axis of the ring) ■ A semicircular or par of a semicircular arc ■ A field due to a finite wire or line charge at a distance that is collinear with the line charge ○ The integral definition of the electric potential due to continuous charge distributions is defined as: $V = \frac{1}{4\pi\varepsilon_0}\int \frac{dq}{r}$ ● Skills			

		○ Apply an appropriate law, definition, or mathematical relationship to solve a problem. ○ Make a scientific claim. ○ Support a claim with evidence from physical representations. ○ Provide reasoning to justify a claim using physical principles or laws			

Unit 8: Conductors, Capacitors and Dielectrics

Enduring Understandings:	Essential Questions:
Excess charge on an insulated conductor will spread out on the entire conductor until there is no more movement of the charge. **Excess charge on an insulated sphere or spherical shell will spread out on the entire surface of the sphere until there is no more movement of the charge because the surface is an equipotential.** **There are electrical devices that store and transfer electrostatic potential energy.** **An insulator has different properties (than a conductor) when placed in an electric field.**	- What are the differences in behavior of charges on a conductor versus an insulator? - How is a microwave able to cook food without transferring energy to objects outside of the microwave? - What properties of a capacitor make it useful in devices like defibrillators? What aspects of the capacitor would you have to change to design a defibrillator to deliver a certain shock? - Why will a charged balloon stick to a non-conducting wall?

Interdisciplinary Connections

HSN-Q.A.1 - Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

HSN-Q.A.2 - Define appropriate quantities for the purpose of descriptive modeling.

Standard Number & Description		Content, Themes, Concepts, and Skills	Teaching Strategies	Instructional Resources and Materials	Assessment Strategies
HS-PS2-6	Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.	Electrostatics with Conductors - Concepts - The mutual repulsion of all charges on the surface of a conductor will eventually create a state of electrostatic equilibrium on the conductor. This will result in a uniform charge density for uniform shapes (spheres, cylinders, planes, etc.) and an absence of an electric field	Predict and Explain Find an enclosed metal wire mesh container that can fit a neon gas discharge tube. Zap the tube with a tesla coil to show it lighting up. Then put the tube in the wire mesh (have students predict what will happen); no amount of effort will cause the tube to light up from the tesla coil. Explain why. Create a Plan	Resources - Knight textbook - AP Classroom - HyperPhysics - PhET Simulations - Pivot Interactives simulations	Daily Do Nows Teacher and peer feedback Exit Tickets Individual activity guided worksheets Lab reports and lab notebook checks
HS-PS3-3	Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.				

HS-PS3-5	Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	inside of all conductors (uniform or nonuniform shapes). ○ A charge can be induced on a conductor by bringing a conductor near an external electric field and then simultaneously attaching a grounding wire/ground to the conductor. ○ The electric field has a value of zero within a spherical conductor. ● Skills ○ Describe the physical meaning (includes identifying features) of a representation. ○ Describe the effects of modifying conditions or features of a representation of a physical situation. ○ Select an appropriate law, definition, mathematical relationship, or model to describe a physical situation. ○ Support a claim with evidence from physical representations. ○ Provide reasoning to justify a claim using physical principles or laws. Capactors ● Concepts ○ The general definition of capacitance is given by the following relationship: $C = \frac{Q}{\Delta V}$ ○ The conservation of charge and energy can be applied to a closed physical system containing charge, capacitors,	Have students research the electric properties of the ionosphere and the Earth's surface and use their research to determine the following: The capacitance of the spherical system consisting of the ionosphere and Earth's surface, and the charge and potential difference of the "capacitor." Desktop Experiment Have students construct their own capacitor and predict its capacitance. Have them use a capacitance-meter to measure the capacitance. Construct an Argument Have students explain why it is that pure water has such a high dielectric constant (answer: the polarity of the molecules). Also have them explain why impure water results in "leaky" capacitors made from a water dielectric (answer: the impurities conduct current). Desktop Experiment Have students construct a parallel-plate capacitor out of two pieces of foil with a piece of paper between each piece. Have students measure the capacitance with a capacitance-meter. Next, have them increase the number of sheets of paper and record data with the purpose of finding the dielectric constant of the paper.	● Physics Classroom simulations ● Mastering Physics Materials ● PASCO data sensors ● Circuit components: batteries, wires, lightbulbs, multimeters, etc. ● PASCO Sparkvue software ● Students supplied devices (Phones, laptops	Progress checks Unit summative test Project rubrics

		and a source of potential difference. ○ The energy of the parallel-plate capacitor can be expressed in terms of the fundamental properties of the capacitor (i.e., area, distance of separation), fundamental properties of the charged system (i.e., charge density), and fundamental constants. ● Skills ○ Describe the physical meaning (includes identifying features) of a representation. ○ Identify a testable scientific question or problem. ○ Make a claim or predict the results of an experiment. ○ Identify or describe potential sources of experimental error. ○ Determine the relationship between variables within an equation when an existing variable changes. ○ Make a scientific claim. ○ Provide reasoning to justify a claim using physical principles or laws. Dielectrics ● Concepts ○ An insulator's molecules will polarize to various degrees (slightly polarize or largely polarize). This effect is determined by a physical constant called the "dielectric constant." The dielectric constant has values between 1 and larger numbers.			

		○ The initial condition of the capacitor system can determine which relationship to use when attempting to calculate unknown quantities in a capacitor system. ● Skills ○ Make a claim or predict the results of an experiment. ○ Sketch a graph that shows a functional relationship between two quantities. ○ Create appropriate diagrams to represent physical situations. ○ Determine the relationship between variables within an equation when an existing variable changes. ○ Calculate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway. ○ Make a scientific claim. ○ Support a claim with evidence from experimental data.			

Unit 9: Electric Circuits

Enduring Understandings:	**Essential Questions:**
• **The rate of charge flow through a conductor depends on the physical characteristics of the conductor.** • **There are electrical devices that convert electrical potential energy into other forms of energy.** • **Total energy and charge are conserved in a circuit containing resistors and a source of energy.** • **Total energy and charge are conserved in a circuit that includes resistors, capacitors, and a source of energy.**	• How do different configurations of resistors and capacitors in DC circuits change the behavior of current flow in the circuit? • How can a DC circuit be designed to power resistors in specific configurations? • What behaviors do capacitors exhibit when included in circuits and what uses do they have?

Interdisciplinary Connections

WHST.9-12.2 - Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

HSN-Q.A.2 - Define appropriate quantities for the purpose of descriptive modeling.

Standard Number & Description		**Content, Themes, Concepts, and Skills**	**Teaching Strategies**	**Instructional Resources and Materials**	**Assessment Strategies**
HS-PS2-6	Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.	Current and Resistance • Concepts ○ The definition of current is: $I = \frac{dQ}{dt}$ ○ Ohm's Law is defined as: $I = \frac{\Delta V}{R}$ ○ The definition of resistance can be derived using the microscopic definition of current and the relationship	Desktop Experiment Give students water, modeling clay, or a related substance and ask them to determine whether the substance is ohmic by applying various voltages and measuring the resulting current. Changing Representations Have students solve a typical multi-loop circuit problem with batteries and resistors. Then have students construct a representation for	Resources • Knight textbook • AP Classroom • HyperPhysics • PhET Simulations • Pivot Interactives simulations	Daily Do Nows Teacher and peer feedback Exit Tickets Individual activity guided worksheets Lab reports and lab notebook checks
HS-PS3-1	Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the				

	other component(s) and energy flows in and out of the system are known.	between electric field and current density. ○ ● Skills ○ Select and plot appropriate data. ○ Extract quantities from narratives or mathematical relationships to solve problems. ○ Apply an appropriate law, definition, or mathematical relationship to solve a problem. ○ Provide reasoning to justify a claim using physical principles or laws. Current, Resistance, and Power ● Concepts ○ The definition of power or the rate of heat loss through a resistor is: $P = I\Delta V$ or an equivalent expressions that can be simplified using Ohm's Law ● Skills ○ Describe the physical meaning (includes identifying features) of a representation.* ○ Demonstrate consistency between different types of representations of the same physical situation. ○ Select relevant features of a representation to answer a question or solve a problem. ○ Identify appropriate experimental procedures (which may include a sketch of a lab setup). ○ Make observations or collect data from representations of laboratory setups or results.	each possible loop that visually shows Kirchhoff's Loop Rule and a representation for each junction that visually shows Kirchhoff's Junction Rule. Construct an Argument Have students explain why a small 1-ohm resistor can only handle a small amount of power (such as 1⁄4 watt) and why a large 1-ohm resistor can handle a large power (such as 30 watts). Have students explain why computer processors have "heat sinks" attached to them. Desktop Experiment Have students use a known capacitor charged and connected directly to a voltmeter to determine the voltmeter's (high) internal resistance. This is done by taking voltage versus time data as the capacitor discharges through the meter and using the data to find the time constant RC, then R.	● Physics Classroom simulations ● Mastering Physics Materials ● PASCO data sensors ● Circuit components: batteries, wires, lightbulbs, multimeters, etc. ● PASCO Sparkvue software ● Students supplied devices (Phones, laptops	Progress checks Unit summative test Project rubrics
HS-PS3-5	Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.				

		○ Select and plot appropriate data. Steady-State Direct-Current Circuits with Batteries and Resistors Only ● Concepts ○ Series arrangement of resistors is defined as resistors arranged one after the other, creating one possible branch for charge flow. ○ Parallel arrangement of resistors is defined as resistors attached to the same two points (electrically), creating multiple pathways for charge flow. ○ In a nonideal battery, an internal resistance will exist within the battery. This resistance will add in series to the total external circuit resistance and reduce the operating current in the circuit. ○ Kirchhoff's Rules allow for the determination of currents and potential differences in complex multi-loop circuits that cannot be reduced using conventional (series/parallel rules) methods. ● Skills ○ Describe the relationship between different types of representations of the same physical situation. ○ Explain modifications to an experimental procedure that will alter results. ○ Represent features of a model or the behavior of a physical system using			

		appropriate graphing techniques, appropriate scale, and units. ○ Identify and describe patterns and trends in data or a graph. ○ Demonstrate consistency between different graphical representations of the same physical situation. ○ Linearize data and/or determine a best fit line or curve. ○ Select relevant features of a graph to describe a physical situation or solve problems. ○ Explain how potential sources of experimental error may affect results and/or conclusions. Capacitors in Circuits ● Concepts ○ The equivalent capacitance of capacitors arranged in series can be determined by the following relationship: $C_S = \sum_i \frac{1}{C_i}$ ○ When a circuit containing resistors and capacitors reaches a steady-state condition, the potential difference across the capacitor can be determined using Kirchhoff's Rules. ○ The time constant (τ = RC) is a significant feature on the sketches for transient behavior in an RC circuits ○ The total energy provided by the energy source (battery) that is transferred into an RC circuit during the charging			

		process is split between the capacitor and the resistor. ● Skills ○ Describe the physical meaning (includes identifying features) of a representation. ○ Select relevant features of a representation to answer a question or solve a problem. ○ Make observations or collect data from representations of laboratory setups or results. ○ Sketch a graph that shows a functional relationship between two quantities. ○ Create appropriate diagrams to represent physical situations. ○ Calculate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway. ○ Support a claim with evidence from experimental data.			

Robbinsville Public Schools

Unit 10: Magnetic Fields

Enduring Understandings:	**Essential Questions:**
Charged particles moving through a magnetic field may change the direction of their motion. **A magnetic field can interact with a straight conducting wire with current.** **Current-carrying conductors create magnetic fields that allow them to interact at a distance with other magnetic fields.** **There are laws that use symmetry and calculus to derive mathematical relationships that are applied to physical systems containing moving charge.**	- With the charge of the electron known, how can a magnetic field be used to determine the mass of the electron? - How can the right hand rule be utilized to predict magnetic fields and forces from current-carrying wires? - In what ways is Ampere's Law similar to Gauss' Law? How is it different?

Interdisciplinary Connections

HSN-Q.A.2 - Define appropriate quantities for the purpose of descriptive modeling.

MP.4 - Model with mathematics

Standard Number & Description		**Content, Themes, Concepts, and Skills**	**Teaching Strategies**	**Instructional Resources and Materials**	**Assessment Strategies**
HS-PS2-5	Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.	Forces on Moving Charges in Magnetic Fields - Concepts - The magnetic force of interaction between a moving charged particle and a uniform magnetic field is defined by the following expression: $\overline{F} = q(\overline{v} \times \overline{B})$ - The direction of the magnetic force is always in a direction perpendicular to the velocity of the moving charged particle. This results in a	Identify Subtasks Have students research some model of old CRT television. Ask them to find the potential difference through which electrons are accelerated to determine their speed entering the magnetic field region, then the strength of the magnetic field needed to deflect them to different points on the screen. Identify Subtasks Have students research the current in an east-west traveling high-tension	Resources - Knight textbook - AP Classroom - HyperPhysics - PhET Simulations - Pivot Interactives simulations	Daily Do Nows Teacher and peer feedback Exit Tickets Individual activity guided worksheets Lab reports and lab notebook checks

HS-PS2-6	Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.	trajectory that is either a curved path or a complete circular path (if it moves in the field for a long enough time). ● Skills ○ Make a claim or predict the results of an experiment. ○ Create appropriate diagrams to represent physical situations. ○ Calculate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway. ○ Make a scientific claim. ○ Support a claim with evidence from physical representations. ○ Provide reasoning to justify a claim using physical principles or laws. Forces on Current-Carrying Wires in Magnetic Fields ● Concepts ○ The definition of a the magnetic force acting on a straight-line segment of a current-carrying conductor in a uniform magnetic field is: $\overline{F_M} = \int I(d\bar{l} \times \bar{B})$ ○ The definition of torque can be applied to the loop to determine a relationship between the torque, field, current, and area of the loop. ● Skills ○ Identify appropriate experimental procedures	power line and find the length of such a power line near their home. Also have them research the magnetic field strength of Earth, and determine the force the Earth's magnetic field exerts on the wire. Compare to the wire's weight. Create a Plan Have students use their research of high-tension power lines to determine how far from such a power line a person must stand before the magnetic field created by the power line is equal to that of the Earth. Have them conduct the same research for the distance from a wire to a hair dryer or vacuum cleaner in the home. Create a Plan Have students research the magnetic field strength of a typical MRI machine, as well as the magnetic field strength of the machine's length and radius. Next, have them determine how that magnetic field can be created with a same-radius, same-length solenoid. Include factors such as length and radius of the wire making the solenoid, its resistance, the current and voltage necessary, and the cost of the wire. Desktop Experiment Obtain a piece of rectangular aluminum foil about 1 foot wide and 2 feet long. Connect it to a battery and resistance (so current travels the long way) and orient it so that current travels toward magnetic north. A compass on the foil should deflect between 30 and 60 degrees (or adjust the voltage/resistance). Have students	● Physics Classroom simulations ● Mastering Physics Materials ● PASCO data sensors ● Circuit components: batteries, wires, lightbulbs, multimeters, etc. ● PASCO Sparkvue software ● Students supplied devices (Phones, laptops	Progress checks Unit summative test Project rubrics
HS-PS3-5	Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.				

		(which may include a sketch of a lab setup). ○ Make observations or collect data from representations of laboratory setups or results. ○ Explain modifications to an experimental procedure that will alter results. ○ Select and plot appropriate data. ○ Apply an appropriate law, definition, or mathematical relationship to solve a problem. ○ Provide reasoning to justify a claim using physical principles or laws. ○ Explain the connection between experimental results and larger physical principles, laws, or theories. ○ Explain how potential sources of experimental error may affect results and/or conclusions. Fields of Long Current-Carrying Wires ● Concepts ○ It can be shown or experimentally verified that the magnetic field of a long, straight, current-carrying conductor is: $B = \frac{\mu_0 I}{2\pi r}$ ○ The field of a long, straight wire can be used as the external field in the definition of magnetic force acting on a segment of current carrying wire. ● Skills ○ Represent features of a model or the behavior of a physical system using	use the compass deflection and Ampere's Law to determine the magnetic field of Earth.		

		- appropriate graphing techniques, appropriate scale, and units. - Sketch a graph that shows a functional relationship between two quantities. - Derive a symbolic expression from known quantities by selecting and following a logical algebraic pathway. - Support a claim with evidence from physical representations. Biot-Savart Law and Ampere's Law - Concepts - The Biot–Savart Law is the fundamental law of magnetism that defines the magnitude and direction of a magnetic field due to moving charges or current-carrying conductors. The law in differential form is: $d\overline{B} = \frac{\mu_0}{2\pi}\frac{I(d\bar{l}\times\hat{r})}{r^2}$ - The Biot–Savart Law can be used to derive the magnitude and directions of magnetic fields of symmetric current-carrying conductors (e.g., circular loops), long, straight conductors, or segments of loops. - Ampère's Law is a fundamental law of magnetism that relates the magnitude of the magnetic field to the current enclosed by a closed imaginary path called an Amperian loop. The			

		law in integral form is: $\oint \overline{B} \cdot d\overline{l} = \mu_0 I$ ○ Ampère's Law can be used to determine magnetic-field relationships at different locations in cylindrical current-carrying conductors. ● Skills ○ Determine or estimate the change in a quantity using a mathematical relationship. ○ Derive a symbolic expression from known quantities by selecting and following a logical algebraic pathway. ○ Make a scientific claim.			

Enduring Understandings:	Essential Questions:
There are laws that use symmetry and calculus to derive mathematical relationships that are applied to physical systems containing a magnetic field. **A changing magnetic field over time can induce current in conductors.** **Induced forces (arising from magnetic interactions) that are exerted on objects can change the kinetic energy of an object.** **Electric and magnetic fields that change over time can mutually induce other electric and magnetic fields.**	- How does magnetic flux compare to electric flux? - How does induction allow for electric motors such as those found in modern electric cars? What different configurations for electric motors exist? - How are LC circuits utilized to create things like radio transmission and theremins? - How is electromagnetic induction utilized in induction heaters?

Interdisciplinary Connections

WHST.9-12.9 - Draw evidence from informational texts to support analysis, reflection, and research.

HSN-Q.A.3 - Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.

Standard Number & Description		Content, Themes, Concepts, and Skills	Teaching Strategies	Instructional Resources and Materials	Assessment Strategies
HS-PS2-5	Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.	Electromagnetic Induction - Concepts - Magnetic flux is the scalar product of the magnetic-field vector and the area vector over the entire area contained by the loop. The definition of magnetic flux is: $\Phi_B = \int \overline{B} \cdot d\overline{A}$ - Induced currents arise in a conductive loop (or long	Desktop Experiment Have students spin a magnet within a coil of wire and measure the spin rate, area, number of coils, and peak voltage induced. From this, have students estimate the strength of the magnetic field generated by the magnet. Qualitative Reasoning Have students explain qualitatively how electromagnetic braking works, including how electromagnetic brakes are structured, how e-brakes can	Resources - Knight textbook - AP Classroom - HyperPhysics - PhET Simulations - Pivot Interactives simulations	Daily Do Nows Teacher and peer feedback Exit Tickets Individual activity guided worksheets Lab reports and lab notebook checks

HS-PS2-6	Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.	wire) when there is a change in magnetic flux occurring through the loop. This change is defined by Faraday's Law ○ When an induced current is created in a conductive loop, the current will interact with the already-present magnetic field, creating induced forces acting on the loop. The magnitude and directions of these induced forces can be calculated using the definition of force on a current-carrying wire. ● Skills ○ Select relevant features of a representation to answer a question or solve a problem. ○ Describe the effects of modifying conditions or features of a representation of a physical situation. ○ Assess the reasonableness of results or solutions. ○ Make a scientific claim. ○ Explain the connection between experimental results and larger physical principles, laws, or theories. Inductance ● Concepts ○ By applying Faraday's Law to an inductive electrical device, a variation on the law can be determined to relate the definition of inductance to the properties of the inductor: $\varepsilon_i = - L\frac{dI}{dt}$ where L is defined as the inductance of the electrical device	recharge a battery, and how e-brakes can double as electric motors. Desktop Experiment Have students construct their own solenoid (or provide one) and measure its inductance using an RL circuit (measure the time constant and the R to get L). Have them repeat the experiment with iron or steel in the core of the inductor to get the increased L. Graph and Switch Have Student A construct quantitative graphs of current versus time and voltage versus time for Inductor, Resistor 1, and Resistor 2 that shows current/voltage before and after a switch opens/closes. Student B must then construct the circuit with the switch, R1, R2, L. Construct an Argument Have students use Maxwell's equations to construct arguments for the following: Why there can be no magnetic monopoles, what eddy currents are and why they exist, why a surface entirely within conducting material must have zero net charge within, and why there must be electric currents within the Earth's core.	● Physics Classroom simulations ● Mastering Physics Materials ● PASCO data sensors ● Circuit components: batteries, wires, lightbulbs, multimeters, etc. ● PASCO Sparkvue software ● Students supplied devices (Phones, laptops	Progress checks Unit summative test Project rubrics
HS-PS3-3	Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.				
HS-PS3-5	Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.				

		○ The electrical characteristics of an inductor in a circuit are the following: ■ At the initial condition of closing or opening a switch with an inductor in a circuit, the induced voltage will be equal in magnitude and opposite in direction of the applied voltage across the branch containing the inductor. ■ In a steady-state condition, the ideal inductor has a resistance of zero and therefore will behave as a care wire in a circuit. ■ In circuits containing only a charged capacitor and an inductor, the maximum current through the inductor can be determined by applying conservation of energy within the circuit and the two circuit elements that can store energy. ○ Using Kirchhoff's Rules and the general model for an LR circuit, general current characteristics can be determined in an LR circuit			

		in a series or parallel arrangement. ● Skills ○ Select an appropriate law, definition, mathematical relationship, or model to describe a physical situation. ○ Apply an appropriate law, definition, or mathematical relationship to solve a problem. ○ Calculate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway. ○ Provide reasoning to justify a claim using physical principles or laws. Maxwell's Equations ● Concepts ○ Maxwell's Laws completely describe the fundamental relationships of magnetics and electric fields in steady-state conditions, as well as in situations in which the fields change in time. ● Skills ○ Describe the effects of modifying conditions or features of a representation of a physical situation. ○ Linearize data and/or determine a best fit line or curve. ○ Explain how the data or graph illustrates a physics principle, process, concept, or theory. ○ Derive a symbolic expression from known quantities by			

		selecting and following a logical algebraic pathway. ○ Provide reasoning to justify a claim using physical principles or laws.			

Unit 12: Conclusions and Summative Project

Enduring Understandings:	Essential Questions:
• **There are many notable physicists that come from a myriad of backgrounds and identities.** • **Physics is a broad subject with many facets and subtopics.**	• What other scientists have contributed to the field of physics that aren't as commonly discussed? • Within the field of physics, what other interesting things are there to study?

Interdisciplinary Connections

RST.11-12.1 - Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

WHST.9-12.7 - Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

WHST.11-12.8 - Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.

Standard Number & Description		Content, Themes, Concepts, and Skills	Teaching Strategies	Instructional Resources and Materials	Assessment Strategies
HS-PS4-3	Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some	Discover scientists not often discussed in the context of physics topics covered by this class. • Due to the scope of this course (foundational physics before the advent of modern physics), many scientists that have contributed to the field of physics go unnamed.	Notable Physicist Project • Students will pick a scientist to research from a list of underrepresented scientists in the field of physics, astronomy, or other related fields.	Resources • Knight textbook • AP Classroom • HyperPhysics • PhET Simulations	Daily Do Nows Teacher and peer feedback Exit Tickets Individual activity guided worksheets

	situations one model is more useful than the other.	• What other scientists from diverse backgrounds have contributed to our understanding of physics? Dive deeper into physics to find other, interesting fields within the subject. • Physics is a very broad field, and this class is designed to cover the fundamental building blocks of the science. • What other fields exist with physics? What is being researched today? How are we using these fields to discover new things or create new inventions?	• Students will create a small presentation based on the scientist they chose. Physics Phenomenon Project • Students will choose a physics topic that was not covered in the year to research and report upon. • Students can create a small presentation, a video, a skit, ot other forms of demonstrating understanding of the material.	• Pivot Interactives simulations • Physics Classroom simulations • Mastering Physics	Lab reports and lab notebook checks Progress checks Unit summative test Project rubrics
HS-PS4-4	Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter				
HS-PS4-5	Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.				

Social Emotional Learning Connections
Below are the five core SEL Competencies as outlined by CASEL, and examples of how each may be addressed within this curriculum
Self-awareness: The ability to accurately recognize one's emotions and thoughts and their influence on behavior. This includes accurately assessing one's strengths and limitations and possessing a well-grounded sense of confidence and optimism. **Example 1:** AP Physics C is a demanding and self-driven class. The pacing of this course and the difficulty of the material will require students to understand their limitations and when to ask for assistance. **Example 2:** Students explore how to utilize their strengths in the setting of a collaborative group environment to generate solutions.
Self-management: The ability to regulate one's emotions, thoughts, and behaviors effectively in different situations. This includes managing stress, controlling impulses, motivating oneself, and setting and working toward achieving personal and academic goals. **Example 1:** Students will develop a broader understanding of how they prefer to complete work by working through difficult course work and quick pacing. **Example 2:** Students will practice self-management through guided and open inquiry labs where they are tasked to explore phenomena.
Social awareness: The ability to take the perspective of and empathize with others from diverse backgrounds and cultures, to understand social and ethical norms for behavior, and to recognize family, school, and community resources and supports. **Example 1:** Students frequently collaborate with peers and consider the thoughts and feelings of others while observing different perspectives. **Example 2:** Students build self-confidence and social awareness through class presentations and the study of scientists that contributed to physics.
Relationship skills: The ability to establish and maintain healthy and rewarding relationships with diverse individuals and groups. This includes communicating clearly, listening actively, cooperating, resisting inappropriate social pressure, negotiating conflict constructively, and seeking and offering help when needed. **Example 1:** Students must practice communication skills while working cooperatively with peers on various problems in the lab environment. **Example 2:** Students must practice group management skills to create a productive lab environment.
Responsible decision-making: The ability to make constructive and respectful choices about personal behavior and social interactions based on consideration of ethical standards, safety concerns, social norms, the realistic evaluation of consequences of various actions, and the well-being of

self and others.

Example 1: Students must practice safe behavior in the lab environment.
Example 2: Students consider the consequences of various decisions while problem solving and researching as they relate to academic integrity and personal ethics.

Integration of 21st Century Themes and Skills

See: [Career Readiness, Life Literacy Skills & Key Skills]

NJSLS-CLKS 9.4: Life Literacies and Key Skills	
Creativity and Innovation	*See specific standards and their connections/examples for this disciplinary concept listed within each individual unit* Can be found in units: 1, 6, 12
Critical Thinking and Problem Solving	*See specific standards and their connections/examples for this disciplinary concept listed within each individual unit* Can be found in units: 2, 5, 7, 9, 10, 11
Digital Citizenship	*See specific standards and their connections/examples for this disciplinary concept listed within each individual unit* Can be found in units: 6, 12
Global and Cultural Awareness	*See specific standards and their connections/examples for this disciplinary concept listed within each individual unit* Can be found in unit: 7, 11, 12
Information and Media Literacy	*See specific standards and their connections/examples for this disciplinary concept listed within each individual unit* Can be found in unit: 1, 6, 12
Technology Literacy	*See specific standards and their connections/examples for this disciplinary concept listed within each individual unit* Can be found in unit: 1, 12

Robbinsville Ready 21st Century Skill Integration

The following skills will be embedded throughout the curriculum and instruction of this course.

Collaborative Team Member: Robbinsville students will learn more by working together than in isolation. As educational theorist Lev Vygotsky advocated, learning is a social process. Many workplaces today encourage employees to work in teams to solicit diverse perspectives, brainstorm new ideas and/or products, and solve problems. Further, collaboration fosters interpersonal relationships, self-management skills, cooperation, and a sense of collective responsibility. Collaborative team members are able to work with diverse groups of people who hold a variety of perspectives.

Effective Communicator: Robbinsville students must be able to clearly articulate their ideas orally, in writing, and across various media in order to successfully connect to the world around them. As the world becomes increasingly globalized, communication is more than just sharing one's ideas. Effective communicators are able to communicate their convictions, actively listen and analyze others' work to identify perspective and/or potential bias.

Emotionally Intelligent Learner: Robbinsville students who are emotionally intelligent learn to be empathetic, demonstrate integrity and ethical behavior, are kind, are self-aware, willing to change, and practice self-care. They are better able to cope with the demands of the 21st century digital society and workplace because they are reliable, responsible, form stable and healthy relationships, and seek to grow personally and professionally. Emotionally intelligent people are able to manage their emotions, work effectively on teams and are leaders who can grow and help to develop others.

Informed and Involved Citizen: Robbinsville students need to be digital citizens who are civically and globally aware. The concept of what it means to be "literate" has evolved along with 21st century technological and cultural shifts. Our progressive vision of literacy entails having our students explore real world problems in the classroom. Informed and involved citizens are able to safely and accurately communicate with people all around the world and are financially, environmentally and informationally literate.

Innovative Thinker: Robbinsville students must encompass innovative thinking skills in order to be successful lifelong learners in the 21st century world. As stated by Karl Fisch and Scott McLeod in the short film Shift Happens, "We are currently preparing students for jobs that don't yet exist . . . using technologies that haven't been invented . . . in order to solve problems we don't even know are problems yet." Innovative thinkers are able to think analytically, solve problems critically, creatively engage in curiosity and tinkering, and demonstrate originality.

Resilient and Self-Directed Learner: Robbinsville students need to take risks and ultimately make independent and informed decisions in an ever-changing world. Author of Life, the Truth, and Being Free, Steve Maraboli stated, “Life doesn’t get easier or more forgiving, we get stronger and more resilient.” Self-directed scholars of the 21st century are able to set goals, initiate resolutions by seeking creative approaches, and adjust their thinking in light of difficult situations. Resilient students are able to take risks without fear of failure and overcome setbacks by utilizing experiences to confront new challenges. Resilient and self directed scholars will consistently embrace opportunities to initiate solutions and overcome obstacles.

Career Awareness and Planning Standards	
Act as a responsible and contributing community member and employee.: Students understand the obligations and responsibilities of being a member of a community, and they demonstrate this understanding every day through their interactions with others. They are conscientious of the impacts of their decisions on others and the environment around them. They think about the near-term and long-term consequences of their actions and seek to act in ways that contribute to the betterment of their teams, families, community and workplace. They are reliable and consistent in going beyond the minimum expectation and in participating in activities that serve the greater good.	Students reflect on their obligations to the classroom community and time is dedicated to examining how our conduct and contributions to the learning process impact those around us and the productivity of the class/group/school community as a whole.
Attend to financial well-being: Students take regular action to contribute to their personal financial well-being, understanding that personal financial security provides the peace of mind required to contribute more fully to their own career success.	Time is dedicated to exploring how and why we work. What about working makes us feel good? What are we uncomfortable with? How can work in this particular content area contribute to the financial security of those working in this industry?
Consider the environmental, social and economic impacts of decisions: Students understand the interrelated nature of their actions and regularly make decisions that positively impact and/or mitigate negative impact on other people, organization, and the environment. They are aware of and utilize new technologies, understandings, procedures, materials, and regulations affecting the nature of their work as it relates to the impact on the social condition, the environment and the profitability of the organization.	Students understand that each action has a consequence that can be positive or negative. This impact exists within the classroom & the workplace, but also reverberates in our communities, our state, our nation and our world. As a result, workplaces and classrooms have procedures and regulations for the wellbeing of all.
Demonstrate creativity and innovation: Students regularly think of ideas that solve problems in new and different ways, and they contribute those ideas in a useful and productive manner to improve their organization. They can consider unconventional ideas and suggestions as solutions to issues, tasks or problems, and they discern which ideas and suggestions will add greatest value. They seek new methods, practices, and ideas from a variety of sources and seek	Students are provided with the opportunity to think creatively to solve problems. There is consistent opportunity for innovation in both individual and in a group setting.. Peer feedback is encouraged to allow for revisions of proposals and

to apply those ideas to their own workplace. They take action on their ideas and understand how to bring innovation to an organization.	to troubleshoot potential solutions to problems as they arise.
Utilize critical thinking to make sense of problems and persevere in solving them: Students readily recognize problems in the workplace, understand the nature of the problem, and devise effective plans to solve the problem. They are aware of problems when they occur and take action quickly to address the problem; they thoughtfully investigate the root cause of the problem prior to introducing solutions. They carefully consider the options to solve the problem. Once a solution is agreed upon, they follow through to ensure the problem is solved, whether through their own actions or the actions of others.	The integration of problem based learning throughout this curriculum provides students with the opportunity to recognize specific problems and take action through thoughtful investigation and problem solving strategies to make meaningful, sustainable change.
Model integrity, ethical leadership and effective management: Students consistently act in ways that align personal and community-held ideals and principles while employing strategies to positively influence others in the workplace. They have a clear understanding of integrity and act on this understanding in every decision. They use a variety of means to positively impact the directions and actions of a team or organization, and they apply insights into human behavior to change others' actions, attitudes and/or beliefs. They recognize the near-term and long-term effects that management's actions and attitudes can have on productivity, morals and organizational culture.	This course provides students opportunities to work collaboratively, rotating from leadership to subordinate roles within the group. Through this structure, students learn how to work with others and gain valuable insights into human behavior and its impact on others' actions, attitudes and/or beliefs.
Plan education and career paths aligned to personal goals: Students take personal ownership of their own education and career goals, and they regularly act on a plan to attain these goals. They understand their own career interests, preferences, goals, and requirements. They have perspective regarding the pathways available to them and the time, effort, experience and other requirements to pursue each, including a path of entrepreneurship. They recognize the value of each step in the education and experiential process, and they recognize that nearly all career paths require ongoing education and experience. They seek counselors, mentors, and other experts to assist in the planning and execution of career and personal goals.	What do we need to do physically and emotionally to prepare to accomplish our goals? Students will regularly participate in goal setting exercises. They will create action plans to accomplish said goals.
Use technology to enhance productivity, increase collaboration and communicate effectively: Students find and maximize the productive value of existing and new technology to accomplish workplace tasks and solve workplace problems. They are flexible and adaptive in acquiring new technology. They are proficient with ubiquitous technology applications. They understand the inherent risks-personal and organizational-of technology applications, and they take actions to prevent or mitigate these risks.	Students will be presented with access to a variety of technological opportunities throughout this course and empowered to utilize the technology to increase collaboration and communicate with their peers.

Work productively in teams while using cultural/global competence: Students positively contribute to every team, whether formal or informal. They apply an awareness of cultural differences to avoid barriers to productive and positive interaction. They find ways to increase the engagement and contribution of all team members. They plan and facilitate effective team meetings.	Students will work productively in culturally and socioeconomically diverse groups of individuals. Through these activities, they will gain an awareness of cultural difference and find ways to increase the engagement and contribution of all team members by introspection and continued reflective practices that examine what we each contribute to a group and what we need from our teammates.

Diversity, Equity & Inclusion Mandate Guide *Robbinsville Public Schools believes that our similarities make us stronger and commits to creating an accessible, inclusive, and connected community where all individuals fully belong and are empowered to contribute and grow. This curriculum meets the New Jersey Department of Education mandats set forth in the Amistad Law, AAPI Law. Holocaust Law and LGBT and disabilities law. Samples of learning for these historically underrepresented groups are embedded throughout this curriculum with key examples highlighted below.*	
AAPI (K-12)	Students will be able to explore the contributions of AAPI scientists to the field of physics in the final unit where they will be tasked to research a scientist and their contributions to the field of physics.
Diversity & Inclusion Law (K-12)	AP Physics C embodies inclusivity by providing physics through the lens of culturally informed pedagogy. Student backgrounds are represented and included in varied problem sets, and students are able to explore the world of physics by relating to aspects in their own lives. Additionally, students will be able to explore the diversity within the field of physics through the scientist research project.

General Differentiated Instruction Strategies	
• Leveled texts • Chunking texts • Choice board • Socratic Seminar • Tiered Instruction • Small group instruction • Guided Reading • Sentence starters/frames • Writing scaffolds • Tangible items/pictures • Adjust length of assignment	• Repeat, reword directions • Brain breaks and movement breaks • Brief and concrete directions • Checklists for tasks • Graphic organizers • Assistive technology (spell check, voice to type) • Study guides • Tiered learning stations • Tiered questioning • Data-driven student partnerships • Extra time

Possible Additional Strategies for Special Education Students, 504 Students, At-Risk Students, and English Language Learners (ELLs)			
Time/General	**Processing**	**Comprehension**	**Recall**
• Extra time for assigned tasks • Adjust length of assignment • Timeline with due dates for reports and projects • Communication system between home and school • Provide lecture notes/outline	• Extra Response time • Have students verbalize steps • Repeat, clarify or reword directions • Mini-breaks between tasks • Provide a warning for transitions • Reading partners	• Precise step-by-step directions • Short manageable tasks • Brief and concrete directions • Provide immediate feedback • Small group instruction • Emphasize multi-sensory learning	• Teacher-made checklist • Use visual graphic organizers • Reference resources to promote independence • Visual and verbal reminders • Graphic organizers
Assistive Technology	**Assessments and Grading**	**Behavior/Attention**	**Organization**

• Computer/whiteboard • Tape recorder • Spell-checker • Audio-taped books	• Extended time • Study guides • Shortened tests • Read directions aloud	• Consistent daily structured routine • Simple and clear classroom rules • Frequent feedback	• Individual daily planner • Display a written agenda • Note-taking assistance • Color code materials

Enrichment
The goal of Enrichment is to provide learners with the opportunity to participate in extension activities that are differentiated and enhance the curriculum. All enrichment decisions will be based upon individual student needs. • Show a high degree of intellectual, creative and/or artistic ability and demonstrate this ability in multiple ways. • Pose questions and exhibit sincere curiosity about principles and how things work. • The ability to grasp concepts and make real world and cross-curricular connections. • Generate theories and hypotheses and pursue methods of inquiry. • Produce products that express insight, creativity, and excellence. • Possess exceptional leadership skills. • Evaluate vocabulary • Elevate Text Complexity • Inquiry based assignments and projects • Independent student options • Tiered/Multi-level activities • Purposeful Learning Center • Open-ended activities and projects • Form and build on learning communities • Providing pupils with experiences outside the ‘regular’ curriculum • Altering the pace the student uses to cover regular curriculum in order to explore topics of interest in greater depth/breadth within their own grade level • A higher quality of work than the norm for the given age group. • The promotion of a higher level of thinking and making connections. • The inclusion of additional subject areas and/or activities (cross-curricular). • Using supplementary materials in addition to the normal range of resources.

English Language Learner (ELL) Resources :

General Supports

- WIDA Can Do Descriptors
- WIDA Can Do Descriptors - Cheat Sheet
- Ways to Support ELLs with Visuals
- Activate Background Knowledge
- Glossary of ELL friendly strategies and activities

Technology based supports

- Virtual Supports and Accommodations for ELL with Technology Specific Supports - Slides presentation
- Translate Google Doc - Directions
- Read Write - Chrome Extension -Text to speech and speech to text
- Mercury Reader - Chrome Extension - cleans up webpages, removes ads, adjusts font and text size, and offers printing optimization
- Text Compactor - simplifies reading level of texts by creating summary sentences based on the frequency of words appearing in the text. This tool works best with expository text.
- Rewordify - simplifies key terms. The reworded words are highlighted (see example to the right with yellow highlighting). There are a few different options for how the changes are shown. Students can click highlighting to hear and see the original words. The site also offers "learning sessions" to help students learn new words from the text they chose to paste on the site. Rewordify documents can be saved and shared.
- Simplish.org - uses an 850 word vocabulary and a scientific dictionary to simplify texts. Any scientific terms are explained in footnotes and students can create their own personal dictionary as they learn new words.
- WordSift.org - input text - it pulls out academic vocabulary and creates a word cloud

Supports by English Level

- ELs Expectations and Modifications by Level
- Blooms for ELLs by Level

- Leveled Questions for ELLs with Bloom

Supports by Domain - Listening, Speaking, Reading, Writing

- Speaking Expectations by Level
- Sentence frames by level for Speaking
- Scaffolds - Receptive and Productive Language
- Writing Rubric Using WIDA Levels

Vocabulary Specific Support

- Vocabulary Scaffold Ideas
- Frayer Model Graphic Organizer
- ELL Dictionary - Google Sheet Self Populating
- Virtual World Wall Template

Content Specific Support

- Considerations when teaching Science to ELLs
- Math/ Science Reference Sheet
- Physics Lab Equipment
- CER Graphic Organize
- Speak like a Scientist Sentence Frames

Special Education Resources

- Animoto -Animoto provides tools for making videos by using animation to pull together a series of images and combining them with audio. Animoto videos or presentations are easy to publish and share. https://animoto.com
- Bookbuilder -Use this site to create, share, publish, and read digital books that engage and support diverse learners according to their individual needs, interests, and skills. http://bookbuilder.cast.org/
- CAST -CAST is a non-profit research and development organization dedicated to Universal Design for Learning (UDL). UDL research demonstrates that the challenge of diversity can and must be met by making curriculum flexible and responsive to learner differences. http://www.cast.org
- CoSketch -CoSketch is a multi-user online whiteboard designed to give you the ability to quickly visualize and share your ideas as images. http://www.cosketch.com/
- Crayon -The Crayon.net site offers an electronic template for students to create their own newspapers. The site allows you to bring multiple sources together, thus creating an individualized and customized newspaper. http://crayon.net/ Education Oasis -Education Oasis offers a collection of graphic organizers to help students organize and retain knowledge – cause and effect, character and story, compare and contrast, and more! http://www.educationoasis.com/printables/graphic-organizers/
- Edutopia -A comprehensive website and online community that increases knowledge, sharing, and adoption of what works in K-12 education. We emphasize core strategies: project-based learning, comprehensive assessment, integrated studies, social and emotional learning, educational leadership and teacher development, and technology integration. http://www.edutopia.org/
- Glogster -Glogster allows you to create "interactive posters" to communicate ideas. Students can embed media links, sound, and video, and then share their posters with friends. http://edu.glogster.com/?ref=personal
- Interactives – Elements of a Story -This interactive breaks down the important elements of a story. Students go through the series of steps for constructing a story including: Setting, Characters, Sequence, Exposition, Conflict, Climax, and Resolution. http://www.learner.org/interactives/story/index.html
- National Writing Project (NWP) -Unique in breadth and scale, the NWP is a network of sites anchored at colleges and universities and serving teachers across disciplines and at all levels, early childhood through university. We provide professional development, develop resources, generate research, and act on knowledge to improve the teaching of writing and learning in schools and communities. http://www.nwp.org
- Pacecar -Vocab Ahead offers videos that give an active demonstration of vocabulary with audio repeating the pronunciation, definition, various uses, and synonyms. Students can also go through flash cards which give a written definition and visual representation of the word. http://pacecar.missingmethod.com/